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THE BROAD-BEAN WEEVIL.

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INTRODUCTION.

The growing of broad or horse beans in California during the last few years has been seriously handicapped everywhere by the presence of the broad-bean weevil (*Bruchus rufimanus* Boh.). The practical impossibility of growing uninfested beans caused the early abandonment of a considerable acreage. The greatest abandonment, however, followed the ruling, according to the Federal Food and Drugs Act, that weevil-infested broad beans are adulterated food, and that their shipment was prohibited in interstate commerce.

The Bureau of Chemistry first ruled that beans infested "to any material extent" could not be shipped (4),[1] but later changed the ruling to allow shipment to any lot which contained "not more than 15 per cent of wormy or weevil-infested beans" (5). The 15 per cent limit is tentative only. Acting under this ruling, a shipment of broad beans from a San Francisco broker was seized in New York, after having been found to be over 25 per cent infested. The broker was tried for violating the Food and Drugs Act, convicted

[1] Numbers in parentheses refer to "Literature cited," p. 22.

by a jury, and fined $150 (9). Since then many dealers have refused to handle horse beans, while those who continued to deal in them have had to exercise caution that no shipment contained more than 15 per cent infested beans, or else run the risk of confiscation. The numerous confiscations during the past few years of shipments in transit by food inspectors, and the cost of hand picking to keep the infestation within the 15 per cent permitted, has resulted in keeping the price of beans low and reducing the acreage.

Although the bean is commonly called the horse bean, the name is somewhat a misnomer, as only about 30 or 40 per cent of the crop is used as stock feed. The larger portion is shipped to New York and other eastern cities, where it is used for food by Italians and Portuguese, and is known as fava. Other names are English bean, Windsor bean, and tick bean.

The horse bean is used also as a green vegetable, and of late years has been planted to a considerable extent as a winter cover crop, especially in fruit orchards. A recent Farmers' Bulletin (8) recommends further plantings along the Pacific coast, the Gulf of Mexico, and the South Atlantic States, not only for the dry beans for human consumption, but also for the green vegetable, stock feed, and green manuring.

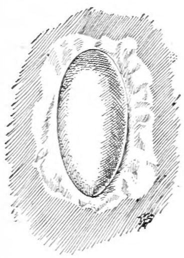


FIG. 1.—The broad-bean weevil: Egg. Greatly enlarged. (Chittenden.)

DESCRIPTION.

THE EGG.

The egg (fig. 1) is elliptical-ovate, about twice as long as wide, a trifle more pointed anteriorly, its surface smooth with no visible sculpture. When first laid it is whitish and glistening, but gradually turns darker. Just before hatching, the black head of the embryo can be seen plainly through the shell.

THE LARVA.

The young larva is pale yellow, with dark or black head and mouth-parts. The full-grown larva is cream colored, with small brown head and black mouth-parts. It is 4.5 to 5.5 mm. long and 2.5 to 3 mm. wide.

THE PUPA.

The pupa when first formed is light yellow or cream colored, with legs and wing-covers whiter. It gradually turns darker, particularly the appendages, until it is light brown before transforming. It measures about 3 mm. wide and 5 mm. long.

THE ADULT.

The adult (fig. 2) is from 3.5 to 4.5 mm. long and a little over half as wide. The general color is black, with white markings on the elytra and pygidium, giving it a somewhat mottled grayish appearance. The head is dark. The basal four joints of the antennæ are reddish brown, the remainder black. The forelegs are reddish brown and black, while the middle and hind pairs are black.

The species closely resembles the pea weevil (*B. pisorum* L., fig. 3), but may be separated by the following characters:

Posterior femora acutely dentate; thorax broad; pattern of elytra well defined; pygidium with a pair of distinct apical black spots____________________*pisorum* L.
Posterior femora obtusely or obsoletely dentate; thorax narrow; pattern of elytra more or less suffused; pygidium with black apical spots lacking or illy defined_______________________________*rufimanus* Boh.

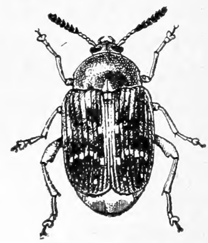


FIG. 2.—The broad-bean weevil (*Bruchus rufimanus*): Adult or beetle. Enlarged. (Chittenden.)

SYNONYMY.

Bruchus rufimanus Boheman.

Bruchus rufimanus Schoenherr, Gen. et Spec. Curculionidum, v. 1, p. 58, 1833.
Bruchus granarius auct. (not L.) Westwood, Curtis, Ormerod, Wood, Riley, Fletcher, Lintner, *et al.*
Mylabris rufimana Boh., Baudi, Deutsch. Ent. Zeitschr., 1880, p. 404.

The *Bruchus granarius* L. is *Laria atomaria* L., Syst. Nat., 12th ed., p. 605, 1776–1778.

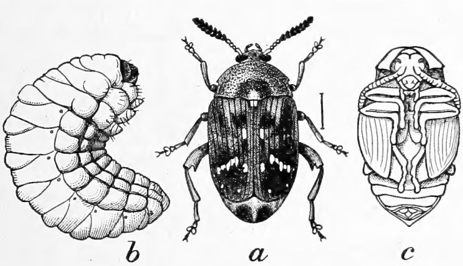


FIG. 3.—The pea weevil (*Bruchus pisorum*): *a*, Beetle; *b*, larva; *c*, pupa. Enlarged. (Chittenden.)

RECORDS OF OCCURRENCE IN CALIFORNIA.

Although horse beans were grown in California as early as 1887, the horse-bean weevil was not recorded as actually established in the United States until September 18, 1909. On that date Mr. I. J. Condit, then collaborator of the Bureau of Entomology, collected live specimens at San Luis Obispo, on growing horse beans (2, 3). Inquiry by the writer among buyers and growers indicates that the weevil was established in California many years before 1909. Mr. P. G. Hammer, San Francisco, writes as follows, "We are quite positive of the date, for in our dealing with this variety of beans the first indication of weevil infestation appeared possibly not later

than 1888," from Alameda County. One other broker gives 1893 as the first date infested beans were observed by him from the same locality. Mr. E. A. Bunker, from a personal transaction in 1898, positively remembers that date as the first year infested horse beans were observed by him. Other dates for the different localities given by different bean brokers are as follows: Gilroy, 1890; Watsonville, 1900; Morro, 1900; Oceano, 1903; Halfmoon, 1904; and Sacramento, 1908.

It must be remembered that in none of the above dates were the weevils in horse beans identified as *Bruchus rufimanus*, but there is little doubt that this is what they were. It is, therefore, quite evident that the insect was present in the different localities a number of years before September, 1909.

DISTRIBUTION IN CALIFORNIA.

The principal broad-bean sections in California are around San Francisco Bay and down along the coast to a little below San Luis Obispo. The insect is distributed all over this section, having been taken or reported from the following counties: Sonoma, Napa, Yolo, Sacramento, San Joaquin, San Mateo, Alameda, Santa Cruz, Santa Clara, San Benito, Monterey, and San Luis Obispo (fig. 4). Broad beans are grown in small quantities in many other counties, usually in back yard gardens or in small plots for the green beans. Of late years, in several counties, they have been quite extensively planted as cover crops, particularly in citrus orchards. Unless great care is exercised, which is not often done, in planting uninfested or treated seed, it is safe to say that the broad-bean weevil will be found wherever broad beans are grown and allowed to come to maturity. The writer has found eggs on the green pods of broad beans planted for cover crops in Los Angeles, Orange, and Riverside counties. Cover crops, however, are all plowed under before the weevil has had a chance to develop.

SPREAD IN CALIFORNIA.

The broad-bean weevil probably became established in Alameda County, where horse beans were first grown, about 1888. It next appeared in Santa Clara County in 1890, and in Santa Cruz, Santa Clara, and San Luis Obispo Counties in 1900. By 1904 it was reported from San Mateo County; by 1911 from Sacramento and Sonoma, by 1914 from Yolo and San Benito, by 1916 from San Joaquin, and by 1917 from Napa.

DISSEMINATION.

Although the adult insect is an active creature and doubtless can fly some little distance, from one field to another, or from where beans may be stored to a near-by field, the principal method of dis-

semination is through the transportation from one locality to another of beans infested with live weevils. It is possible for the adults to escape both after the beans have reached their destination and while they are en route. Planting of these infested beans in a new locality is bound to result in an infested crop.

FIG. 4.—Map of California, showing counties from which the broad-bean weevil has been taken or reported.

NATURE OF DAMAGE.

Damage caused by the broad-bean weevil is principally due to the fact that the larva feeds and transforms to the adult within the beans (Pl. I, fig. 3, *a*, *b*). Many adults remain in the beans for several months, and their presence renders the beans unfit for food. Some adults emerge soon after forming, leaving round holes in the

beans where the tissue was consumed by the larvæ (Pl. I, figs. 4, *a*, *b*, and 5). This "buggy" appearance lessens the salability of the beans. Infested beans are not only reduced somewhat in weight (see Table I) but their germinating power is also lessened, as will be shown later on.

TABLE I.—*Showing amount of beans consumed by the broad-bean weevil.*

Number of weevils in beans.	Weight of 50 beans.	Weight consumed.	Percentage consumed.
	Grams.	*Grams.*	
None	76,970		
1	74,800	2,170	2.81
2	72,430	4,540	5.89
3	70,150	6,820	8.86

This table shows that approximately 3 per cent of the weight of a bean is consumed by the larva of each weevil developing in it.

EXTENT OF DAMAGE.

It is estimated that the area devoted to broad beans commercially is at present about 3,000 acres for the dry beans, 100 acres for canning green, and 1,000 acres for cover crops. In addition many hundreds of acres are grown in small lots, back-yard gardens, etc., for home consumption. The commercial production of dry beans for market is at present about 50,000 bags, but has been, before weevil damage became so general, as much as 200,000 bags.

After a careful survey of the 1916, 1917, and 1918 crops of horse beans, and of numerous samples taken by food inspectors of the Bureau of Chemistry and the writer, Tables II and III were prepared.

TABLE II.—*Summary of the percentage of infestation of the 1916, 1917, and 1918 crops of broad beans grown in California.*

Infestation.	1916 crop.		1917 crop.		1918 crop.	
	Number of bags.	Per cent of total crop.	Number of bags.	Per cent of total crop.	Number of bags.	Per cent of total crop.
0 to 5 per cent	18,851	38.10	15,372	46.46	6,638	26.75
5.1 to 10 per cent	8,366	16.88	6,855	20.71	5,341	16.16
10.1 to 15 per cent	6,835	13.81	4,904	14.82	4,629	14.01
15.1 to 30 per cent	11,114	22.46	4,852	14.66	10,547	31.93
Above 30 per cent	4,318	8.75	1,107	3.35	3,681	11.15
Total	49,474	100.00	33,090	100.00	33,036	100.00

The damage according to the different horse-bean regions is shown in the following table:

TABLE III.—*Summary of the 1916, 1917, and 1918 crops of broad beans showing the percentage of weevil infestation by localities.*

	1916 infestation.	1917 infestation.	1918 infestation.
Sacramento:	*Per cent.*	*Per cent.*	*Per cent.*
Maximum	41	63	84.3
Minimum	0	0	1
Average	9.09	12.7	22.4
Oceano-Morro:			
Maximum	50	63	17.2
Minimum	0	0	0
Average	14.5	14.5	2.92
Halfmoon:			
Maximum	55	56.6	56
Minimum	0	.5	0
Average	13.6	10.9	16.8
Gilroy:			
Maximum	70	46	....
Minimum	0	1	....
Average	24	16	....

Table II shows that of the entire crop of broad beans for the three years 1916, 1917, and 1918, 31.21, 18.01, and 43.08 per cent, respectively, were above the 15 per cent limit of weevil infestation allowed by the Bureau of Chemistry, and therefore could not be shipped unless hand picked. Table III shows that even the average percentage of infestation for the entire 1916 crop in the Halfmoon and Gilroy regions was above the 15 per cent limit, while the same is true of the Sacramento and Halfmoon districts for the 1918 crop. This table also shows some interesting data on the increase in infestation. Sacramento is a comparatively new district for raising broad beans, and at first the weevil infestation was low, but as planting continued from year to year, and the acreage increased, the percentage of infestation greatly increased, going from a maximum of 41 per cent in 1916 to 63 per cent in 1917 and 84.3 per cent in 1918, while the average percentage of infestation for the same years increased from 9.19 to 12.7, and then to 22.4 per cent. Climatic conditions at Sacramento are adverse to late planting, and early planting as practiced there is favorable to heavy weevil infestation. Unless control measures are practiced, and only uninfested or treated seed is planted, this district soon will be in the same position in regard to the production of horse beans that Alameda County has been in for some years. The low percentage of infestation in the Oceano-Morro district for the year 1918 will be explained later.

Estimates from bean brokers on the reduction in value of broad beans from the infestation of the weevil vary from 25 per cent to total unsalability, depending on the degree of infestation.

The cost of hand picking to remove the weevily beans also depends on the degree of infestation, but it is estimated at about $1.50 per 100 pounds.

Estimates of the reduction on the total horse bean acreage, because of the increase in weevil infestation, range from 25 to 75 per cent. Alameda County was formerly the largest producer, but at present, due largely to the extensive infestation of all horse beans grown there, practically no beans are produced commercially. It is also estimated that if weevil infestation could be prevented, the acreage for the dry-bean crop alone would be increased from 100 to 300 per cent in that county.

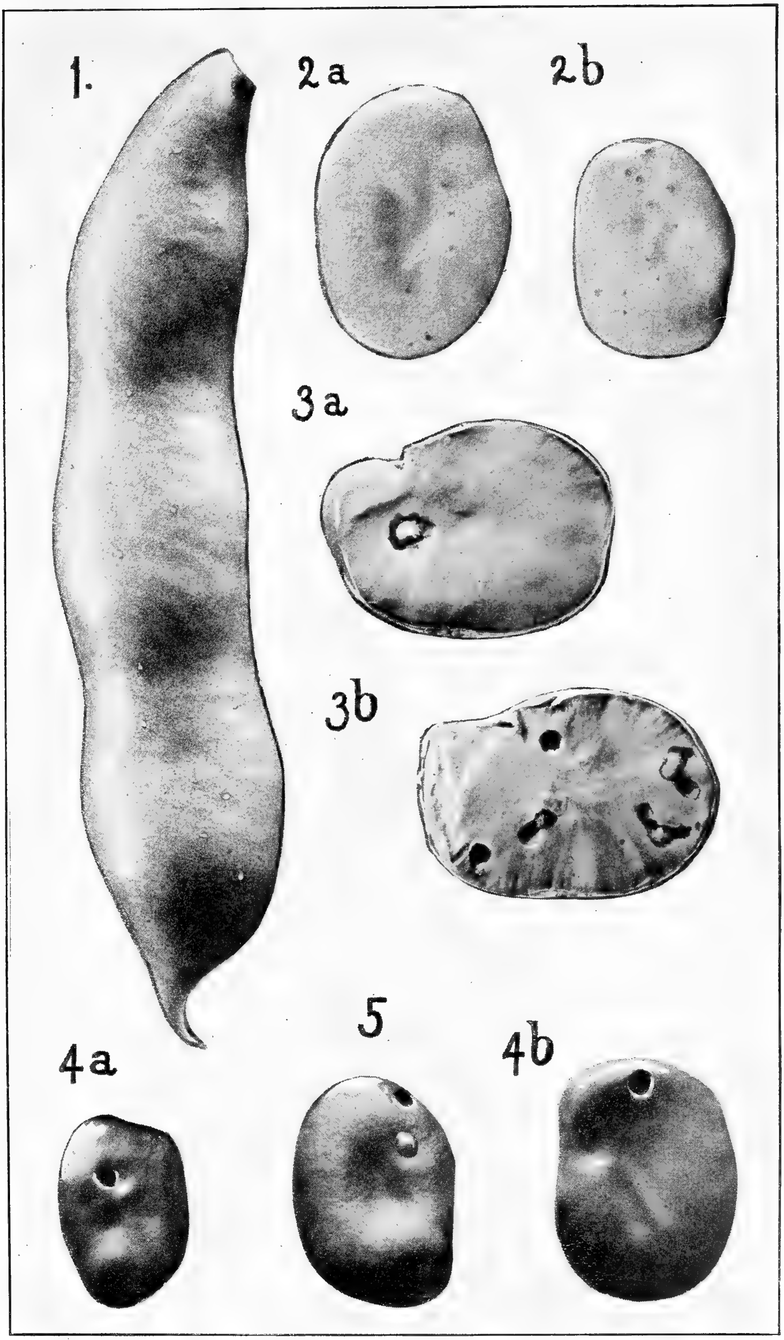
It will be seen from Table III that there is considerable variation in the percentage of infestation in the different districts. There is also great variation in the number of weevils developing in a single bean. In the case of the pea weevil *B. pisorum* (fig. 3), with a very similar appearance and life history, only one weevil develops in a seed, but with the broad-bean weevil there are often two and three adults in a single bean, while it is not at all rare to find four, five, and even six. The following table illustrates this:

TABLE IV.—*Summary of the percentage of broad beans infested with different number of weevils.*

Number beans examined.	Locality raised.	Year raised.	Number weevils per bean.	1 weevil per bean.	2 weevils per bean.	3 weevils per bean.	4 and 5 weevils per bean.	Total per cent infested.
1,000	Hayward	1915	371	367	186	63	13	62.9
1,000	do	1916	331	324	216	95	34	66.9
1,000	do	1917	781	164	46	9	0	21.9
1,000	Stockton	1917	880	105	14	1	0	12
1,000	Hayward	1917	573	227	140	29	31	42.7
Average per cent			58.9	23.7	12	3.9	1.5	41.1

LIFE HISTORY.

The eggs are laid on the outside of the green pods, being cemented to the latter by a glutinous secretion. They are laid singly and indiscriminately over the surface of the pods (see Pl. I, fig. 1) without apparent reference as to whether the position is favorable or unfavorable to the newly hatched larva getting into the young bean. The number of eggs on a pod also bears no relation to the number of beans it contains, as often the former exceeds by many times the number of larvæ which might develop therein. One pod 4 inches long was observed with 55 eggs deposited on it. The following table shows the variation in number of eggs laid on a pod.



THE BROAD-BEAN WEEVIL.

1, Broad-bean pod showing eggs laid upon its surface; 2, broad beans showing entrance holes or "stings" of larvæ; 3, *a*, *b*, broad beans cut open to expose larvæ of the broad-bean weevil and the damage they have done; 4, 5, infested broad beans showing emergence holes made by adult weevils in leaving the seed. In figure 5, below the emergence hole, is shown a "window."

TABLE V.—*Number of eggs of Bruchus rufimanus deposited on pods at Hayward, Calif.*

Date.	Number pods on plant.	Total number eggs per plant.	Number eggs per pod.		
			Maximum.	Minimum.	Average.
1916.					
April 20	12	88	17	2	7.3
Do	19	153	17	1	8
April 25	5	30	18	2	6
Do	12	70	29	1	5.8
Do	14	119	22	1	8.5
Do	8	71	19	4	8.8
Do	8	48	9	3	6
Do	11	115	23	2	11.3
Do	10	144	42	8	14

No eggs were observed by the writer except on the pods, the latter varying in size from less than an inch to full growth of 5 inches. Most of the eggs are found on the larger pods.

Although adults have been noticed a number of times crawling over the plants during the day, the act of oviposition was never observed. It is probable that it occurs late in the evening or at night.

Efforts to induce oviposition in captivity were not successful, so the total number of eggs laid by individual females was not ascertained.

The duration of the egg stage was found to be from 9 to 18 days, with an average of 13 days. A few days before hatching the dark head of the embryonic larva can be seen plainly through the egg-shell. The larva draws its head back, leaving about one-quarter of the shell hollow. For about a day the position appears to be unchanged, then gradually as the larva eats through the side of the shell attached to the pod and into the pod the clear space in the shell becomes larger until the latter is entirely empty, having a glassy and transparent appearance. It usually takes about two days from the time the larva begins eating through the shell until it is entirely out of the latter and into the bean pod.

The young larva begins feeding when the bean is green, and it is well along toward maturity before the bean dries up. The amount of food consumed is small compared with what other insects eat. It appears that the young larva often eats out a short tunnel, advancing a little distance from the point where it entered the bean. When the larva gets larger it eats out a hole somewhat its own shape, and about 50 per cent larger, as is shown in Plate I, figure 3, *a* and *b*.

When the larva reaches maturity, and just before pupating, it eats out a round hole in the cotyledon, directly under the epidermis. The hole is plainly seen through the half-transparent skin or "window," which is broken easily by the adult weevil when it is ready to emerge (see upper beans in Pl. I, fig. 5). The hole is seldom at the spot where the larva entered, but at varying distances from it. The

point where the young larva entered, sometimes called the "sting," plainly shows on the dry bean as a dark spot varying in size from a pinpoint to almost as large as a pinhead. This is illustrated in Plate I, figure 2, *a* and *b*.

Mortality among the larvæ after entering the beans is rather high. This is so both in the case where by far more larvæ enter a bean than could develop in it, and in the case where only one or two larvæ enter, although the percentage of mortality is less with the latter than with the former. Table VI graphically illustrates this point:

TABLE VI.—*Comparison of the number of larvæ of Bruchus rufimanus entering beans with the number reaching maturity.*

Number of beans.	Number of larvæ entering beans.	Number of adults.	Maximum number of larvæ entering a bean.	Average number of larvæ entering a bean.	Average number reaching maturity.	Percentage of larvæ entering beans reaching maturity.	Percentage of beans entered by larva.	Percentage of beans infested with adults.
100	263	132	10	2.63	1.32	50.1	85	70
100	199	95	7	1.99	.95	47.7	78	63
100	226	86	16	2.26	.86	38	80	58
100	72	16	9	.72	.16	22.2	40	15
100	54	29	5	.54	.29	53.6	39	26
Average	162.4	71.6	9.4	1.62	.71	42.3	64.4	46.4

It will be seen from the table that although as many as 16 larvæ may enter a single bean, the average number is about 2, and a total average of a little over 40 per cent reach maturity. Comparison with Table IV shows that while a maximum of from 5 to 16 larvæ may enter a bean, the percentage of beans containing more than 2 adults is small.

The larval stage is from 10 to 15 weeks, the average being about 12 weeks.

Immediately after eating out the round hole in the cotyledon, already referred to, the full-grown larva becomes quiet, and in a short time pupates. At first the pupa is the same color as the larva, but gradually turns darker until it is a dark brown.

The pupal stage is from 7 to 16 days with an average of 10 days.

When the adult is first formed it is light brown and very soft, but it gradually turns darker and becomes harder. The adult may soon eat its way out of the bean through the "window" prepared by the larva, or it may remain in the bean for several months. In fact many adults never emerge from the beans at all, but die in them. If the weather is warm, or the beans are handled much, the weevils are apt to emerge from the beans sooner and in greater numbers than if the weather is cool and the beans are not handled much. Many of the adults emerge from the beans after the latter have been planted. The duration of the adult stage varies considerably, de-

pending on the weather conditions, from one month to a possible eight months. Table VII gives a summary of the life-history records.

TABLE VII.—*Life history of the broad-bean weevil in California.*

Locality.	Eggs laid.	Hatched.	Duration of egg stage.	Pupated.	Duration of larva stage.	Adult.	Duration of pupa stage.	Died.	Duration of adult stage.	Total length of life.
	1917.	1917.	*Days.*	1917.	*Days.*	1917.	*Days.*		*Days.*	*Days.*
Pasadena	May 3	May 15	12	Aug. 19	96	Aug. 27	8	Sept. 27, 1917	31	147
Hayward	May 11	May 24	13	Aug. 29	98	Sept. 8	10	Feb. 8, 1918	152	273
Hayward	....	....	......	Sept. 3	......	Sept. 12	9	Dec. 7, 1917	86	......
	1918.	1918.		1918.		1918.				
Alhambra	Apr. 9	....	......	July 26	......	Aug. 4	10	....	......	......
Alhambra	...do....	....	......	Aug. 5	......	Aug. 21	16	....	......	......
Alhambra	...do....	....	......	Aug. 22	......	Aug. 30	8	....	......	......
Alhambra	Apr. 28	May 5	9	Aug. 5	90	Aug. 12	7	Apr. 23, 1919[1]	253	359
Alhambra	May 6	May 17	11	...do....	80	...do....	7	Dec. 26, 1918	137	235
Alhambra	May 7	May 20	13	Aug. 22	94	Aug. 30	8	May 31, 1919[1]	274	393
Alhambra	Apr. 28	May 7	9	Aug. 12	97	Aug. 28	16	....	......	......
Alhambra	May 17	May 27	10	Sept. 10	106	Sept. 17	7	....	......	......
Alhambra	May 17	June 2	16	Aug. 5	64	Aug. 13	8	Dec. 6, 1918	114	203
Alhambra	May 17	June 4	18	Aug. 30	87	Sept. 13	14	Nov. 30, 1918	78	197
Alhambra	Mar. 14	Mar. 28	14	....	......	....	......	....	......	......
Averages	....	....	12.5	....	90	....	10	....	140	258

[1] Theoretical, showing possible life history from two records.

SEASONAL HISTORY.

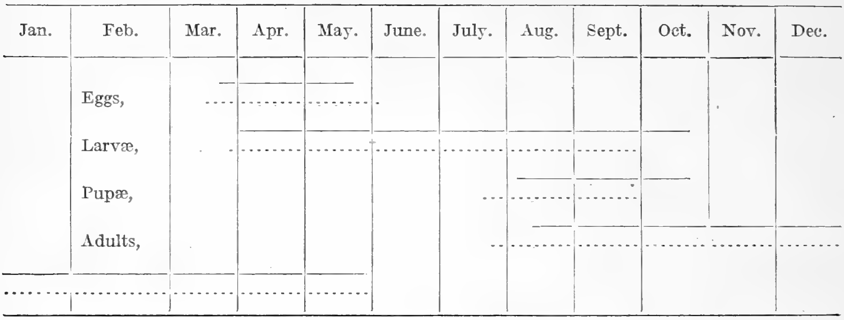
Egg laying begins about the middle of March, is heaviest in April, and extends a little beyond the middle of May. The larval period is from the latter part of March to the middle of October. Pupæ can be found from the first of August to the latter part of October, and adults from the middle of August to about the following June. Tables VIII and IX show the actual records of the seasonal history for 1917 and 1918.

TABLE VIII.—*Seasonal history of Bruchus rufimanus in Pasadena and Alhambra, Calif.*

Year.	First eggs observed.	Last eggs observed.	First eggs hatched.	Last eggs hatched.	First full-grown larvæ.	Last full-grown larvæ.	First pupa.	Last pupa.	First adult.	Last adult.
1917	Mar. 23	May 20	....	....	Aug. 1	Oct. 19	Aug. 3	Oct. 22	Aug. 10	(1)
1918	Mar. 14	May 19	Mar. 28	June 4	July 16	Sept. 26	July 18	Sept. 28	July 25	....

[1] About June 1, 1918.

TABLE IX.—*Graphic chart of life history of Bruchus rufimanus for seasons of 1917–18 and 1918–19.*



Continuous line=1917–18. Broken line=1918–19.

Although a few adults may be found as late as June, the majority die before the end of March. During 1917 a number of badly infested beans were inclosed in a box. Ten per cent of the weevils were dead by February 1, 50 per cent by March, and 90 per cent by the 1st of April. A very few remained alive until June. The results of field observations at Hayward during 1918 as to the prevalence of weevils in the fields are recorded in figure 5. Each count represents an examination of horse-bean plants for a period of 15 minutes.

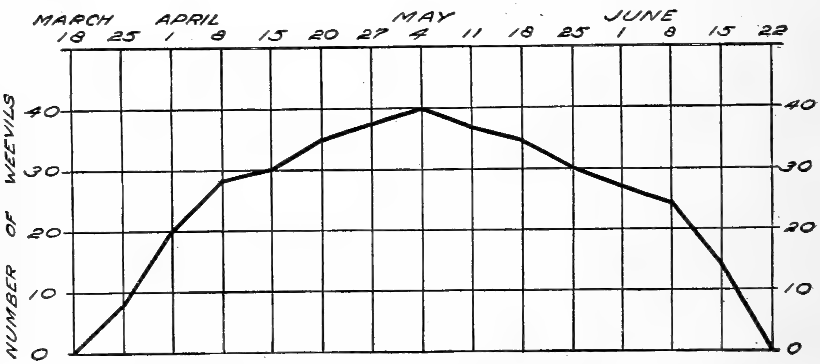


FIG. 5.—Curve showing abundance of broad-bean weevils in a field at Hayward, Calif., 1918.

Adults have never been observed in the field before the latter part of March, but it is evident that some of them must live through the winter, hiding in the soil, or among rubbish, leaves, etc. In experimental plantings of infested beans, both in the fields and in pots, live adults have been observed to come out of the soil several days after planting. In one case a germinating bean was dug up two weeks after it had been planted, and a live weevil, which had emerged from the bean, was found clinging to it. In another germination

test, beans were taken from pots 20 days after planting, and a live adult found in one of its burrows in a bean that had germinated.

When disturbed, the weevils have the habit of folding their legs tightly and feigning death. On the plant they will fall to the ground, but quickly become active. In the sack or on a table they are apt to remain quiet, "playing possum" for some time, and it takes quite a prod with a pencil or pin to make them become active.

GERMINATION TESTS OF INFESTED BEANS.

A number of tests were made to determine the effect of weevil infestation on the germinating power of the beans and at the same time compare new seed and that held over a year.

TABLE X.—*Germination tests of infested and noninfested beans; new and year-old seeds.*

Date.	New crop seed, percentage of germination—					Date.	Old crop seed, percentage of germination—				
	With no weevil.	With 1 weevil.	With 2 weevils.	With 3 weevils.	With 4 and 5 weevils.		With no weevil.	With 1 weevil.	With 2 weevils.	With 3 weevils.	With 4 and 5 weevils.
Apr. 26, 1916	98	90	60	72	......	Oct. 27, 1916	96	94	86	88	......
Nov. 20, 1916	98	92	68	98	......	Nov. 20, 1916	100	90	90	90	75
Dec. 1, 1916	96	94	86	88	......	Dec. 1, 1916	90	70	90	90	......
Dec. 13, 1916	86	60	54	50	......	Dec. 13, 1916	88	64	56	......	......
May 8, 1916	100	100	92	92	87	Mar. 22, 1918	84	72	80	24	44
Mar. 22, 1918	92	88	88	73	......	Oct. 17, 1918	100	38	54	8	......
Oct. 17, 1918	98	68	26	28	52						
Apr. 28, 1916	98	90	88	68	70						
Average	95.7	82.7	72.7	71.1	69.6	Average	93	71.1	76	60	59
Average of infested beans					74	Average of infested beans					66

This table shows that as the number of insects per bean increases, the percentage of germination decreases. The drop is about 20 per cent from perfect beans to those infested with one weevil, and somewhat less for each weevil up to the maximum of 4 and 5 weevils, which gives a germination of 60 or 70 per cent. The table also shows that the percentage of germination is a little more with new crop seeds than with those held over for a year.

The table, however, does not show the reason for the low germination in the infested beans. In only a few cases does the insect actually injure the embryo or germ, but by far the greatest damage comes from the fact that the holes made by the insects allow bacteria or fungi to enter, which cause the beans to rot. In a number of cases rotting takes place soon enough to prevent germination entirely, but a large number of beans are killed also after the seed has actually germinated, and before the shoot can get out of the ground. Rotting of the seed is much worse during cool or cold weather, when germi-

nation is slow, than during warm weather, when germination takes only a few days. One germination experiment had to be discarded, as rotting of the seed was practically 100 per cent. In another test, the soil was sterilized with formalin, and germination was perfect, not only with uninjured beans, but also with those having 1, 2, and 3 weevils in them. Those having 4 and 5 weevils gave a 92 per cent germination, the balance being injured in, or too close to, the germ.

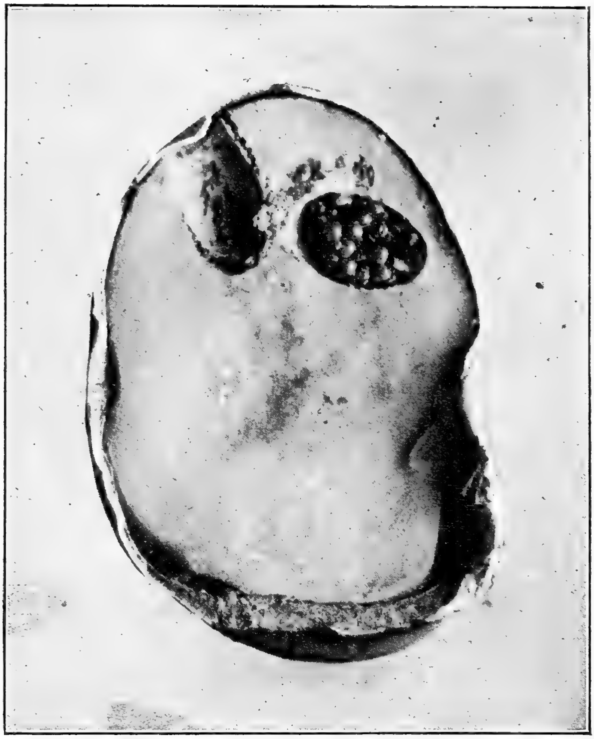


FIG. 6.—Broad bean cut in half to show pupal cell of the broad-bean weevil containing predacious mite (*Pediculoides ventricosus*). Enlarged. (Chittenden.)

Whether infested beans produce weak plants or small crops, was not determined, but it was observed many times that the sprouts from infested beans were much less vigorous than those from perfect beans.

NATURAL ENEMIES.

The only natural enemy of *Bruchus rufimanus* observed during the investigation was a predacious mite, *Pediculoides ventricosus* Newport (fig. 6). This was observed a number of times, but only a small fraction of 1 per cent of the insects were affected. Mr. W. B. Parker reports having observed a beetle in the clutches of the

ruduviid bug *Zelus renardii* Kolen. Several hymenopterous parasites[1] are recorded by European writers, but have not been observed in this country.

CONTROL MEASURES.

It is obviously impossible, at least from a practical standpoint, to prevent infestation of the beans in the field by such methods as the application of poisons or deterrents. Any control measures, therefore, must be toward keeping the adults from getting into the fields, or, in other words, must consist of planting seed which contains no live weevils.

Mr. W. B. Parker reports good success in treating infested beans with water heated to about 150° F. (160° and over affects germination) for from 15 to 20 minutes. This might do for small gardens, but is obviously impractical for commercial plantings.

DRY HEAT.

A series of experiments was carried on to determine the degree of heat and the length of time required to kill the weevils. Preliminary experiments showed that exposing infested beans to from 120° to 160° F. for from 5 to 40 minutes did not kill all the weevils. Following is the result of the final experiment. Heat was supplied by electricity. For each test a sack of about 2 pounds of beans was used in a fumigating box with a capacity of 60 cubic feet. Later the beans were carefully examined to find whether they contained live or dead weevils.

TABLE XI.—*Effect of dry heat on the broad-bean weevil.*

Date treated.	Date examined.	° F.	Time treated.	Result.
1917.	1918.		*Minutes.*	
Nov. 15	Mar. 28	160	30	Some alive.
Oct. 24	do	160	40	Do.
Oct. 20	do	160	40	Do.
Nov. 15	do	170	20	Do.
Oct. 24	Mar. 5	170	20	Do.
Do	Mar. 28	170	25	All dead.
Oct. 20	do	170	30	Do.
Nov. 15	do	170	30	Some alive.
Oct. 20	Mar. 5	170	40	All dead.
Nov. 15	Mar. 28	180	15	Some alive.
Do	Mar. 5	180	20	All dead.
Aug. 24	Mar. 28	180	20	Some alive.
Sept. 19	do	180	30	Do.
Oct. 24	Feb. 27	180	30	All dead.
Oct. 20	Mar. 28	180	40	Do.

These experiments indicate that dry heat is not a satisfactory remedy for the broad-bean weevil, because in order to be effective it has to be so high that the germinating power of the beans may be

[1] *Sigalphus pallipes* Nees, *Sigalphus thoracicus* Curt., *Chremylus rubiginosus* Nees (1, p. 57).

destroyed. The experiments were carried on mostly in the fall, shortly after all the adults had formed. Other experiments during the spring, toward the end of the life of most of the weevils, gave a complete killing with a lower degree of heat and a shorter time.

Treatment of from 125° to 145° F. for several hours, as recommended for bean and pea weevils in a recent Farmers' Bulletin (7), was not tried. Experiments indicated, however, that the horse-bean weevil is more difficult to kill than the ordinary bean weevil. Unless the heat can be easily controlled and not allowed to go much above 145°, other remedies will be much safer to use.

FUMIGATION.

Sulphur was first tried, using varying strengths up to 2 pounds to 100 cubic feet of space for a period of 3 hours, and proved unsuccessful.

The standard remedy for bean weevils, carbon disulphid, was next tried. The experiments were arranged to compare the effect of infested beans fumigated while the insects were in the immature stages and after all had reached the adult stage. Examination of beans during the experiment gave the following results:

TABLE XII.—*Development of Bruchus rufimanus Aug. 15 and 17, 1918, at Alhambra, Calif.*

	Per cent.
One-half to three-fourths grown larvæ	37.6
Full grown larvæ	20.9
Total larvæ	58.5
Pupæ	20.
Adults	21.5

TABLE XIII.—*Effect of carbon disulphid on the broad-bean weevil.*

Pounds CS_2 per 1,000 cubic feet.	Percentage of beans with all weevils dead.			
	Exposed 18 hours.		Exposed 24 hours.	
	Treated in August.	Treated in October.	Treated in August.	Treated in October.
Check, not treated	43	14	43	14
2	55		52	
3	55		52	
4	69	83	60	81
5	70	94	82	96
6	60	90	62	99
7	74	100	79	100
8		99		100
9, 10, 12, 15, 20		100		100

Conclusions from the carbon disulphid fumigation experiments:

1. Exposure in October when the insects were in the adult stage gave a 20 per cent better result than in August, when they were in the larval stage.

2. A 24-hour exposure gave only about 2 per cent better results than one of 18 hours.

3. A 48-hour exposure gave about a 5 per cent better result than one of 24 hours.

4. Seven pounds to 1,000 cubic feet for 24 hours was the least amount to give a 100 per cent killing.

5. Germination is not affected by the treatment, as beans treated with 15 and 20 pounds per 1,000 feet for 24 hours gave 95 and 97 per cent germination.

Contrary to expectations, it was found that fumigating while the insects were in the larval stage was less effective than in the adult stage. A glance at Table XII will show that when the first fumigation took place in August, almost 40 per cent of the larvæ were not full grown. These were still eating within the bean, and had not come up to the epidermis and formed the "window" through which the adult emerges. It is evident, therefore, that the gas can not penetrate into the interior of the beans to the partially grown larvæ as easily as it can reach the full-grown larvæ, pupæ, or adults directly under the skin.

It was further observed that in the beans fumigated in August a number of full-grown larvæ and pupæ had been killed.

Lengthening the time of exposure did not greatly increase the percentage killed. This conforms to the opinions of Dr. W. E. Hinds (6) of the Alabama Experiment Station, who says, "As a matter of fact, most, if not all, of the killing will have occurred during the first 6 hours of the exposure, and the building may be ventilated after that time, as a minimum, has elapsed, although it is better to wait 12 hours or longer." On the effect of carbon disulphid on the germination of the seeds, Dr. Hinds states: "It would appear from numerous tests that there is practically no danger of injuring germination in treating seeds that are well matured and dried out before treatment is given. *It would not be wise to treat moist seeds, or planting seed of any kind, during periods of very humid atmosphere*, as the seeds might take up enough moisture to make them liable to injury from the vapor."

HOLDING OVER SEED.

Life-history studies showed that the horse-bean weevil had but one generation a year, that it did not breed in the dry beans, and that the last few remaining live adults died by the 1st of July. By merely holding the beans over, therefore, until the second year, they will be uninfested as far as live weevils are concerned. The beans should be stored in sacks or containers tight enough to prevent any live weevils getting out during the first season.

By referring to Table X, it will be seen that the germination of old seed is only slightly less than that of new seed.

Mr. Ronald McKee, in his bulletin on horse beans (8) previously mentioned, states: "Horse-bean seed retains its vitality for a number of years. * * * Germination tests of seed 4 years old of a number of varieties grown at Chico, Calif., showed little or no deterioration."

It can not be emphasized too strongly that any control measures to prevent weevil infestation should be undertaken by the entire community and not by a few growers. If all growers in the horse-bean districts would plant either absolutely uninfested beans, seed which had been given a thorough treatment with carbon disulphid, or seed which had been held over until the second year, the resulting crop would be of a very much higher quality as regards freedom from weevil infestation.

LATE PLANTING.

It has been observed for some time by horse-bean growers and buyers that the crops from seed planted early in the season were likely to be infested more badly than those from seed planted later. In administering the Food and Drugs Act, inspectors of the Federal Bureau of Chemistry collected samples of horse beans from all parts of the State, and ascertained for each sample the time of planting and the percentage of infestation. From the data furnished by them, and from samples taken and tested by the writer, the following tables were compiled. In Table XIV the growers did not know the exact date of planting, but remembered only whether they were planted early or late.

TABLE XIV.—*Comparing the degree of weevil infestation in crops planted early and late. Data from all horse bean districts in California.*

Year.	Planted early.[1]		Planted "later."		Planted late.	
	Number of sacks.	Percentage of infestation.	Number of sacks.	Percentage of infestation.	Number of sacks.	Percentage of infestation.
1916	17,100	32.5			5,380	6.3
1917	1,500	34.3	1,990	18.77	1,960	6.5

[1] Early means previous to January 1; late, subsequent to March 1.

Whenever possible, the month of planting the seed was ascertained in connection with the degree of infestation, and these data are given in Table XV.

TABLE XV.—*Comparing the degree of weevil infestation in horse beans from all districts in California, planted in different months.*

Year.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1916	46	47	15.2	14.4	5.2	9.6	1	0
1917		50	15.6	17.5	8.21	12		
1918		30.1	19.1	18.5	15.7	12.9	4.3	.8
Average		42.3	16.6	16.7	9.7	11.5	2.6	.4

To test this out further, plantings of horse beans were made at Pasadena, Alhambra, and Hayward, for the years 1917 and 1918, in which a certain number of beans were planted each month, and when harvested carefully examined to find out the percentage of infestation. The results are given in Tables XVI and XVII.

TABLE XVI.—*Showing the percentage of weevil infestation of beans planted during certain months at Pasadena and Alhambra.*

Year.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
1917[1]		17	11.5	12	7.5	5	2.6
1918	43.5	45	15.5	8	.75		

[1] Degree of infestation for 1917 crop found by counting larval entrance holes, which are about 50 per cent greater than number of adult weevils.

TABLE XVII.—*Showing the percentage of infestation of beans planted during certain months at Hayward, Calif.*

Year.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
1917				24	18	9.6	9.3
1918	74.5	67.5	32	14	5		

These tables clearly show that the later in the season the seed is planted the lower the percentage of infestation will be. A possible explanation of this may be found by referring to the seasonal history of the insect, which shows that egg laying begins about the middle of March, is heaviest in April, and extends to the middle of May. Figure 5 shows also that at Hayward the first adults were observed in a broad-bean field on March 18 and that the number constantly increased each week to May 4, after which the number decreased as constantly until June 15, the last date any were observed. Since the eggs are laid only on the pods, it follows that any plants which produced pods prior to or during April will be subject to the greatest egg deposition, and pods produced subsequently to the latter part of April would be liable to little or no egg deposition.

Seed planted from October to February begins setting pods in March and April, while seed planted from the latter part of February to May will begin setting pods from the latter part of April to June.

It would seem, therefore, from consulting the tables giving the percentages of infestation for seed planted in different months, from the insect's life history, and from the rate of growth and pod setting by the plant, that whenever possible it will be advisable to delay the planting until from the latter part of February or the first of March to May. A glance at Tables XIV and XVII will show that plantings prior to February and March show much higher percentages of infestation than those planted subsequently.

This contention is further borne out in the experience of the Oceano-Morro district in San Luis Obispo County. It was the custom there to begin planting about November, continuing all winter and spring. For several years the horse beans had been seriously infested with the bean aphis (*Aphis rumicis* L.) which also did severe damage to the later planted crops of small white and pink beans. Assuming that the early planted horse beans acted as a winter host for the bean aphis, propagating it in great numbers before the more extensive plantings of other beans were made, the horticultural commissioner persuaded all horse-bean growers to delay planting in the 1917–18 season until March 1. This agreement was adhered to with a few minor exceptions, and the result is shown in Table III. The maximum and average percentages of infestation for the Oceano-Morro district for 1916 are 50 and 14.5 per cent and for 1917, 63 and 14.5 per cent. In both these years a good share of the crop was from seed planted early, that is, from November to March, but in 1918, when practically no seed was planted until after March 1, the maximum and average per cent of weevil infestations are 17.2 and 2.92, a reduction of over 75 per cent. The majority of the plantings were not infested at all, particularly those which had been planted in April and May.

The planting season begins soon after the first rains, or ordinarily in October and November, in some sections, while in others it is delayed until spring. The former are the drier inland sections where the crop must be matured before the warm dry weather of the early summer, and the latter are the low, cooler, coastal valleys where the summer heat is not high enough to affect the crop.

The earlier plantings, especially in the dryer sections, usually produce larger crops than late plantings. This is particularly true where the beans are raised without irrigation. The climate and soil conditions, therefore, as well as the availability of irrigation water, must be taken into consideration in arranging for a delayed planting program. Where late planting can not be practiced because of these conditions, it is especially important that all seed either be uninfested or treated to kill the weevil before planting; but where conditions are favorable, planting should be delayed as late as is commensurate with getting a good crop.

RECOMMENDATIONS.

Only uninfested or treated horse beans should be used for seed. All horse beans used for seed which are infested with the broad-bean weevil either should be treated with carbon disulphid or held over in tight receptacles until the second year, when the weevils will all be dead.

Carbon disulphid should be used at from 7 to 10 pounds per 1,000 cubic feet, for at least 24 hours, in a box, barrel, or room as air-tight as it is possible to get. The smaller amount is effective in perfectly tight receptacles, but the larger amount should be used if the fumigating box or room is not tight. The liquid should be placed in a shallow pan at the top of the box or poured over the seed.

Infested seed which has not been treated and is held in warehouses or barns near broad-bean fields, except that held over for seed until the second year in tight receptacles, should be disposed of or fed before the planting season.

Badly infested seed should be ground up in feed mills immediately after harvesting.

Planting should be delayed until as late as possible, preferably after March 1. In the dryer and hotter localities where this is not possible, it is especially important to plant only seed which is uninfested or has been treated to kill the weevil.

All growers of horse beans should cooperate in carrying out these measures.

SUMMARY.

Broad-bean growing has been handicapped seriously by the presence of the broad-bean weevil (*Bruchus rufimanus*).

Although the first record of this insect's establishment in America was in 1909, it probably has been here since about 1888.

It is found in the entire broad-bean section of California.

The weevil not only lowers the value of the beans but has greatly reduced the acreage planted to that crop.

The insect has but one generation a year and does not breed in dry beans.

The egg stage is from 9 to 18 days; the larval stage, 10 to 15 weeks; the pupal stage, 7 to 16 days; and the adult stage, 1 to 8 months.

Eggs are laid on the green bean pods in the field from the middle of March to the middle of May; the larvæ reach maturity from August to October, while adults can be found from August to the following June.

Germination of infested beans is from 20 to 40 per cent less than that of uninfested beans.

Germination of seed a year or more old is only slightly less than that of new seed.

There are no natural enemies of the broad-bean weevil of any consequence in America.

It requires 170° to 180° F. for over half an hour to kill all of the weevils in broad beans.

Sulphur is unsatisfactory as a fumigant.

Carbon disulphid at the rate of 7 pounds per 1,000 cubic feet in a tight box for 24 hours kills all the weevils.

In seed held over until the second year all the weevils are dead.

Beans from crops planted late, after March 1, are much less infested than those planted earlier, from November to March.

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